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ScienceDirect
Procedia Computer Science 86 (2016) 128 – 131
Procedia Computer Science

2016 International Electrical Engineering Congress, iEECON2016, 2-4 March 2016, Chiang Mai, Thailand

Effects of Temperature and Channel Doping on the BSIM3 Threshold Voltage Model of NMOSFET form Substrate Bias Dependent Methodology

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Abstract

The effects of channel doping and temperature dependence on the BSIM3 threshold voltage model of NMOSFET form substrate bias dependent methodology is proposed. The I_{DS} -V_{GS} in linear region with different substrate bias condition of a big size of NMOSFET was used. The threshold voltage parameters extraction procedure is based on the measurement of the transconductance characteristics of MOSFET in linear region. The electrical parameters γ, N_{CH} and N_{SUB} also the BSIM3 model parameter K_1 and K_2 at different channel implanted dose and different operating temperature are extracted. The model can be implemented in simulation tools with the error is less than 5% .

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Keywords: NMOSFET; Threshold voltage; BSIM3

1. Introduction

The threshold voltage (V_{TH}) is the one important parameters of MOSFET. The adjustment of threshold voltage was done by the implantation in a channel. In modern CMOS technology fabrication, the use of two implants is done in controlling the threshold voltage and controlling the punch -through effect. In threshold voltage controlling, the implant ions very closed to the surface, then the substrate doping concentration is not increased. To prevent punch –through, the implant ions is much closed to the point of source-drain junction depth, the depletion region

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Peer-review under responsibility of the Organizing Committee of iEECON2016
doi:10.1016/j.procs.2016.05.032

widths should be contained at the point between source and drain end where the punch-through current flow [1]. In NMOS with non uniform channel doping concentration, the implant ions and the substrate doping is the same type. The channel doping concentration is defined by [1]

$$N_{CH} = N_{SUB} + N_I \tag{1}$$

$$\gamma_1 = \frac{\sqrt{2q\varepsilon_{SI} N_{CH}}}{C_{OX}} \tag{2}$$

$$\gamma_2 = \frac{\sqrt{2q\varepsilon_{SI} N_{SUB}}}{C_{OX}} \tag{3}$$

$$\frac{qN_{CH} X_t^2}{2\varepsilon_{SI}} = \Phi_S - V_{BX} \tag{4}$$

Where N_{CH} is an implanted channel doping, N_{SUB} is substrate concentration, N_I is an implanted concentration, γ_1 and γ_2 are a body-bias coefficient when the doping concentration is N_{CH} and N_{SUB} respectively, V_{BX} is the body bias voltage when the depletion width in a channel is equal X_t. In BSIM 3 level, the threshold voltage include non uniform substrate doping is proposed [3]

$$V_{TH} = V_{THO} + K_1\left(\sqrt{\Phi_S - V_{BS}} - \sqrt{\Phi_S}\right) - K_2 V_{BS} \tag{5}$$

$$K_1 = \gamma_2 - 2K_2\sqrt{\Phi_S - V_{BM}} \tag{6}$$

$$K_2 = \frac{\left(\gamma_1 - \gamma_2\right)\left(\sqrt{\Phi_S - V_{BX}} - \sqrt{\Phi_S}\right)}{2\sqrt{\Phi_S}\left(\sqrt{\Phi_S - V_{BM}} - \sqrt{\Phi_S}\right) + V_{BM}} \tag{7}$$

Where the parameter K_1 and K_2 are the first -order body effect coefficient and the second -order body effect coefficient in the non uniform doping MOSFET with the unit of $V^{1/2}$ and none of unit respectively. In this paper, the effects of channel doping and temperature dependence on the BSIM3 threshold voltage model and the extraction methodology are proposed also. The electrical parameters such as γ, N_{CH} and N_{SUB} also the BSIM3 model parameter K_1 and K_2 at different channel implanted dose and different operating temperature are extracted and proposed .

2. Materials and Methods

The testing devices in this paper were fabricated by Twin-Well 0.8 CMOS technology (TMCN08) from Thai Micro Electronics Center (TMEC). The testing devices using a precision semiconductor parameter analyzer B-1500A. From Sentaurus process simulation data, the X_t is approximately 0.15μm [3], the N_{CH} is around 1×10^{17} cm^{-3}, the calculated V_{BX} is approximately -0.37V to -0.6 V which is depended on the surface doping concentration. The threshold voltage measurement method is the linear extrapolation method [5]. The reverse substrate biases start from 0 to 10 V, V_{BS} from 0 to 0.1V with 0.02 V per step, V_{BS} from 0.1 to 1V with 0.1 V per step and V_{BS} from 1 to 10V with 1.0 V per step. Fig.1 shows the simulated step profile concentration in channel. Fig.2 shows the V_{TH} versus $(\Phi_S - V_{BS})^{1/2}$ with the channel doping dose (M) is 1.3×10^{12} cm^{-2}

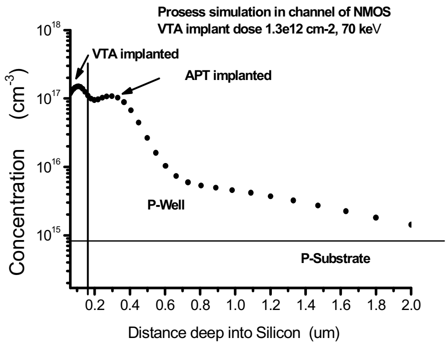

Fig. 1. Simulated concentration profile in channel of NMOS

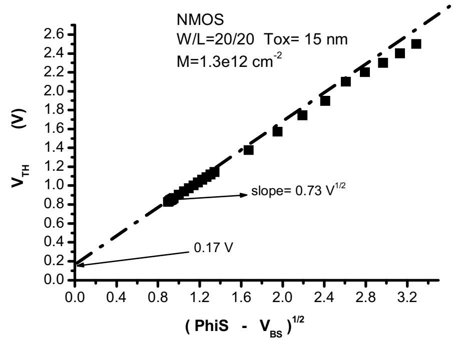

Fig. 2. V_{TH} versus $(\Phi_S - V_{BS})^{1/2}$

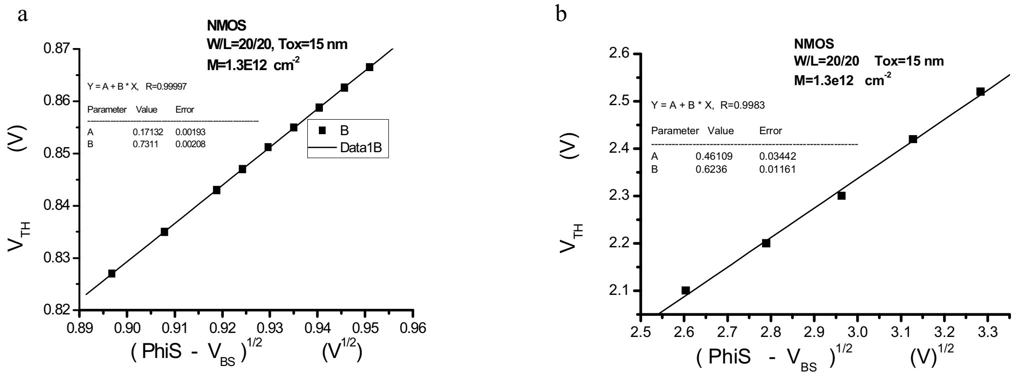

Fig. 3. V_{TH} versus $(\Phi_S - V_{BS})^{1/2}$ at 300 K (a) at surface channel ; (b) deep in p- substrate

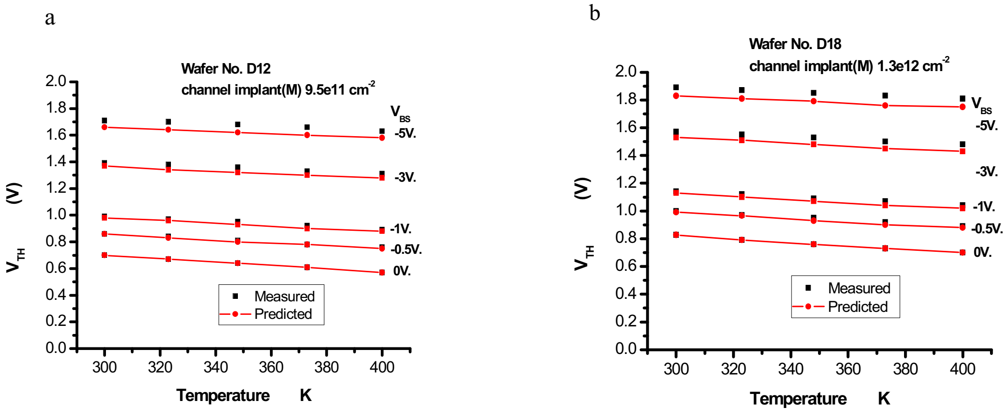

Fig. 4. Measured V_{TH} versus Extracted model of NMOS at various temperature and V_{BS} (a) channel doping 9.5e11 cm-2 ; (b) channel doping 1.3e12 cm-2 respectively

3. Results and Discussion

In Fig. 2, the V_{TH} is almost linear with respect to $(\Phi_S - V_{BS})^{1/2}$ up to the reverse substrate bias of –10.0 V . There are two value of slope, the slope value at the lower V_{BS} ($V_{BS} < V_{BX}$) is more than the slope value at the higher V_{BS}. Due to the doping concentration is normally higher near the surface (V_{TH} adjustment) than the doping concentration deep in to the substrate. Then the parameter γ_1 is larger than the parameter γ_2. By plotting the V_{TH} at the different V_{BS} value versus the $(\Phi_S - V_{BS})^{1/2}$ with the channel implanted dose of 1.3×10^{12} cm^{-2} with 70 keV of energy as shown in Fig.3. We get the parameter N_{CH}, Φ_S and y-intercepted ($V_{FB} + \Phi_S$). The implanted flat-band voltage V_{FB} is calculated from the y- intercepted. In Fig.3 (a) shows the body effects at the surface channel of MOSFET with n+poly silicon gate at 300 K. As you seen that the body-bias coefficient at surface channel γ_1 is around 0.73 V$^{1/2}$, N_{CH} about 8.4×10^{16} cm^{-3} and surface potential Φ_S about 0.81 V. In case of Fig.2 (b), in similarly, the body-bias coefficient of the region deep in to substrate γ_2 is around 0.62 V$^{1/2}$, N_{SUB} about 6×10^{16} cm^{-3}. The BSIM3 model parameter K_1 and K_2 are calculated in Eq.(6) and Eq.(7) respectively.The measured V_{TH} versus the extracted model of NMOS at various temperature and V_{BS} is illustrated in Fig.4. The absolute error between measured and predicted model at various temperatures and at various V_{BS} of the testing devices are less than 5%. As you known that, the parameter K_2 is founded to be a significant value at the V_{BS} is higher as follow in Eq.(5). However, the error is still kept lower than 5%.

4. Conclusions

The effects of channel doping and temperature dependence on the BSIM3 threshold voltage model of NMOSFET form substrate bias dependent methodology is proposed. The extracted threshold voltages are determined from the linear extrapolation methodology. With this method, we can analyze the effect of non uniform doping and the parameter which is depended on the channel doping. The electrical parameter γ, N_{CH} and N_{SUB} also the BSIM model parameter K_1 and K_2 at different channel implanted dose and different operating temperature are extracted. The extraction can be done by manual calculating. The model can be implemented in simulation tools with the error is less than 5% .

Acknowledgements

The authors would like to thank King Mongkut's Institute of Technology Ladkrabang, National Research Council of Thailand and TMEC/NECTEC.

References

1. Tsividis, Operation and Modelling of the MOS Transistor. McGraw-Hill; Singapore:1988.
2. Forty.D, Mosfet Modelling with SPICE Principle and Practice. Prentice Hall; New Jersy:1997.
3. Cheng,Y. and Hu, MOSFET Modelling and BSIM3 User'sGuide. Kluwer publisher;USA:1999.
4. Sze. S M, Phys of semiconductor devices. Wiley John & Sons; New York: 1991.
5. Deiter K. Schroder, Semiconductor Material and Device Characteristics. John Wiley & Son; New-York America:1990.
6. Willey Maes , Lodc Lauwers, SIMPRA II A Parameter Extraction and model Evaluation Software Package. IMEC V.Z.W; Belgium: 1991.